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Calculation of relative electric strength of various gases at atmospheric pressure - An approach

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An attempt has been made here to utilize ionization energy, bond strength and polarizability in Townsend breakdown criteria and to calculate the relative electric strength of gases like N_2, CO_2, CO, C_2H_2, O_2, H_2 and N_2O. The theoretical results have been compared with the experimental values which are in good agreement.

1. Theory

A gas is normally an almost perfect insulator, but some free electrons and ions are usually present. An applied electric field will consequently, result in a current which normally will be very feeble. At sufficiently high field strengths the current is greatly increased because of the occurence of ionization processes. The primary ionizing process in the gas is ionization by collision between neutral gas molecules and free electrons which have been accelerated by the field and thus obtained the necessary ionizing energy. Thus new electron ion pairs are formed and by this cumulative process the number of electrons and ions grows very rapidly and electron avalanches are formed.

According to Townsend theory of electrical breakdown the steady state current flowing in a non-uniform gap is given by

$$\frac{I}{I_0} = \frac{\exp(\alpha d)}{1-\gamma(\exp(\alpha d)-1)}, \tag{1}$$

where I_0 = initial photo-electric current,
d = electrode separation,
α = primary ionization coefficient,
γ = generalized secondary coefficient.

The electrode spacing d_s at which the current becomes self-maintaining and independent of I_0 is given by

$$d_s = \alpha^{-1}\, ln\left(\frac{1+\gamma}{\gamma}\right)$$

and from this the sparking voltage V_s $(= Ed_s)$ can be evaluated. The condition $\gamma(\exp(\alpha d)-1) = 1$ represents the threshold for instability, and this accounts for the close agreement, within the limits of experimental error, between the observed, sparking voltage and values obtained from theory, as shown by Jones *et al* (1952) and Dutton *et al* (1952). The coefficient stated here is frequently referred as the generalized secondary Townsend coefficient of ionization and is further dependent on several parameters which may be written as (Nasser 1970)

$$\gamma = \frac{\beta}{\alpha}+\gamma_i+\gamma_p+\gamma_m+\cdots , \tag{3}$$

where

α = Coefficient of ionization by electron collision,

β = Coefficient of ionization by ion collision,

γ_i = Coefficient of emission of secondary electron owning to positive ion bombardment,

γ_p = Coefficient of emission of secondary electrons owing to photons from the gas,

γ = Coefficient of emission of secondary electrons owing to metastable action.

Further the coefficients $\gamma_p, \gamma_m, \gamma_g$, etc. are dependent on several factors such as the number of excited state owing to electron collision, coefficient of absorption, the number of metastable created by electron impact, geometric factor, etc. Thus it is evident from eq. (3) that the measurement of the coefficient γ which is dependent on various parameters is a difficult task. From the engineering pont of view engineers are less interested to know the various parameters of the coefficient γ, rather they are interested to know the sparking voltage, sparking distance, etc. so as to use a particular gas to serve their purpose. The coefficient which are readily or easily available may be used to calculate the sparking voltage, sparking distance, etc. An equation has been derived (Paul et al 1974) for the calculation of breakdown voltage of gases in terms of ionization potential, bond strength and polarizability. In this paper these parameters are used in Townsend equation to show that they are also valid in Townsend breakdown criteria which may be written as

$$1-\frac{1}{\lambda_2\lambda_3}(\exp(\lambda_1 d)-1) = 0, \quad \ldots \tag{4}$$

where

λ_1 = ionization energy,

λ_2 = bond strength,

λ_3 = polarizability.

From eq. (4) the sparking distance d_s may be written as

$$d_s = \left(\frac{1}{\lambda_1}\right) \ln(1+\lambda_2\lambda_3). \quad \ldots (5)$$

Knowing the value of d_s from eq. (5) the sparkng voltage V_s $(= Ed_s)$ may be calculated. Comparing eqs. (2) and (5) it may be stated that α corresponds to λ_1 and γ corresponds to $(1/\lambda_2\lambda_3)$.

2. Results

Taking nitrogen as unity, eq. (5) has been used to compute the relative electric strength of few gases at atmospheric pressure and the results obtained are tabulated in table 1. The values of λ_1, λ_2 and λ_3 as used in calculation are also displayed in the same table.

Table 1

Gas	Ionisation* potential (λ_1)	Bond** strength (λ_2)	Polarisa-ability** (λ_3)	Relative electric strength (experimental value)	Relative electric strength (calculated value)
1	2	3	4	5	6
N_2	14.48	226	1.76	1.00	1.00
CO_2	14.40	126.9	2.65	0.88	0.95
CO	14.1	256.7	1.95	1.02	1.11
C_2H_2	11.6	194.4	3.33	1.10	1.45
O_2	13.5	118	1.60	0.85	0.82
H_2	15.6	104.2	.79	0.54	0.49
N_2O	12.9	170	3.0	1.14	1.21

*Hodgman (1956), **Chem. Syst. (1964), ***Hirschfelder *et al* (1954).

It is evident from the table 1 (columns 5 and 6) that the results obtained (except C_2H_2) are in close agreement, within the limits of experimental error, between the observed sparking voltage and values obtained from theory. It may be stated here that the values of λ_1, λ_2, λ_3 used in calculation are not available in the same identical condition as a result of which there may be deviation from the experimental values.

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